Investigation of the characteristics of cumulative protons produced as a result of interaction of neutrinos and antineutrinos in the Skat bubble chamber

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The characteristics of cumulative protons produced from freon nuclei (CF_3Br) were investigated at neutrino and antineutrino energies of 2 to 30 GeV using the Skat bubble chamber.

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At present, extensive experimental information on the production of cumulative protons (protons emitted into a kinematic region which is forbidden for scattering by a free nucleon), obtained in hadrons and γ beams, has been accumulated.[1–3] The first results in an antineutrino beam have been obtained.[4] A number of papers[5–7] has been devoted to theoretical interpretation of the production of cumulative protons. No experiment, however, gives as yet unambiguous evidence in favor of some theoretical model that explains this effect. The most basic information for theoretical interpretation can be obtained from processes of deep inelastic scattering of leptons by nuclei, in which fast nucleons emitted in the backward direction in the l.s. can be observed.

The predictions of a number of models for such processes can be reduced to the following effects.[8]

Amado–Woloshyn hypothesis.[5] The cumulative nucleons can be knocked out only due to diffractive-type processes. A decrease of the average multiplicity of hadrons compared to processes involving a free nucleon is predicted. The interaction occurs primarily in the region $x{:}x_{\rm diff} \ll \langle x \rangle$, where $\langle x \rangle$ is the average Bjorken variable for processes involving a free nucleon.

Weber–Miller hypothesis.[6] A sharp suppression of the yield of cumulative nucleons compared to hadron–nuclear interaction processes is predicted. Angular symmetry of the spectrum of cumulative nucleons and an absence of a correlation between the nucleon momentum and the variable x are predicted.

Few-nucleon correlation hypothesis.[7,8] An angular asymmetry of the emission of cumulative nucleons and a correlation between the nucleon momentum and the variable x are predicted:

$$\langle x_\alpha \rangle = (2 - \alpha)\langle x \rangle \qquad \text{(pair correlation)}$$

$$\langle x_\alpha \rangle = (1.5 - \alpha/2)\langle x \rangle \qquad \text{(triple correlation)}$$

where $\alpha = (\sqrt{M^2 + p^2} - p_3)/M$ (M is the nucleon mass and p_3 is the projection of

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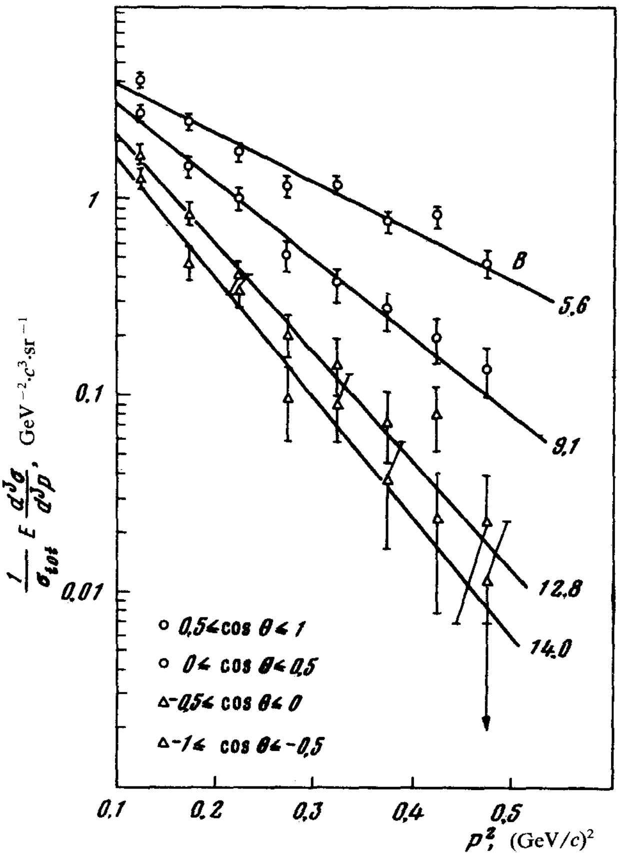

FIG. 1. Momentum spectra of protons in the $\nu_\mu N$ interactions in different regions of the angles of emission θ.

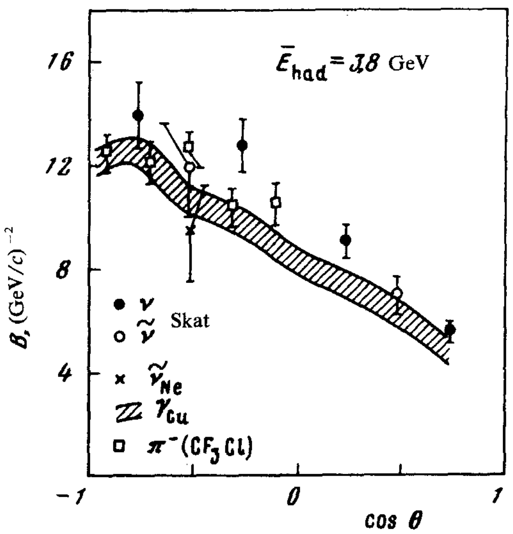

FIG. 2. Angular dependence of the parameter $B(\theta)$; ● and ○ represent our experiment; □, III, and × denote experiments,[2-4] respectively.

TABLE I.

N_p	N_{event}/N_{tot} , %	
	ν_μ	$\tilde{\nu}_\mu$
1	13.6 ±0.9	9.6 ±1.7
2	2,1 ±0.4	2.3 ±0.8
3	0.28 ±0.13	0.29

the nucleon momentum p in the direction $q = p_\nu - p_\mu$) and x_α is the Bjorken variable for processes with cumulative protons.

In this paper we report experimental data obtained from the Skat bubble chamber for production of cumulative protons as a result of interaction of $\nu_\mu(\tilde{\nu}_\mu)$ with CF_3Br nuclei, which are based on the 1868 (ν_μ) and 348 ($\tilde{\nu}_\mu$) *CC* events. The experimental setup and selection of the *CC* events were published elsewhere.[9-11]

The region of investigated proton momenta was limited to the interval $0.1 \leqslant p^2 \leqslant 0.5$ (GeV/c)^2.

Figure 1 shows the momentum distributions of protons for different regions of emission angle (relative to direction of the vector) and the results of a fit in the form:

$$1/\sigma_{tot} E\, d\sigma/d^3p = C\exp(-B(\theta)p^2).$$

The slope parameter $B(\theta)$ increases with increasing angle of emission of the proton θ. The same effect is observed as a result of interaction of hadrons and γ quanta with nuclei.[8]

TABLE II.

		With protons in the background direction	Without protons in the background direction
ν_μ	$\langle N_\pi \rangle$	2.53 ±0.18	2,37 ±0.07
	$\langle N_p \rangle$	2,33 ±0.16	0.58 ±0.03
	$\langle N^s_{\pi^+} \rangle$	0.22 ±0,03	0,21 ±0.01
	$\langle N^s_{\pi^-} \rangle$	0,24 ±0.03	0.12 ±0,01
ν_μ	$\langle N_\pi \rangle$	1.5 ±0.3	1,54 ±0,11
	$\langle N_p \rangle$	2,14 ±0,40	0,39 ±0,04
	$\langle N^s_{\pi^+} \rangle$	0,07 ±0,04	0.07 ±0,02
	$\langle N^s_{\pi^-} \rangle$	0,3 ±0,1	0,21 ±0,03

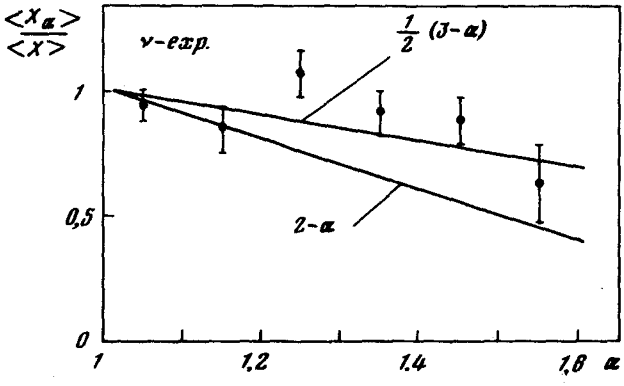

FIG. 3. Dependence of $\langle x_\alpha \rangle / \langle x \rangle$ on the variable α.

Figure 2 shows the angular dependence of the parameter B, which was obtained in different experiments. It can be seen from these data that the experiment performed by using the $\nu_\mu(\tilde{\nu}_\mu)$ beams indicates that the parameter B depends weakly on the type of incident particle.

We give the main characteristics of the reactions associated with formation of cumulative protons ($90° \leqslant \theta \leqslant 180°$). In this experiment we found 286 (41) events of this type in $\nu_\mu(\tilde{\nu}_\mu)$ interactions.

Table I gives the relative yields of the events that contain 1, 2, and 3 cumulative protons.

Table II gives the multiplicities of different type of charged particles for the events that contain cumulative protons and for those that do not contain them.

The average multiplicities in Table II are as follows: $\langle N_\pi \rangle$ is for hadrons (excluding the identified protons), $\langle N_p \rangle$ is for identified protons, and $\langle N^s_{\pi^\pm} \rangle$ is for $\pi^\pm$ mesons with momenta $p_\pi \leqslant 0.25$ GeV/c.

Figure 3 shows the relationship between the momentum of the nucleon and the variable x, and the predictions of the model.[7,8]

In conclusion, we note that the neutrino experiments showed no evidence of a sharp suppression of the yield of cumulative protons compared to the hadronic experiments. The relative yield of such protons in the $\nu_\mu N$ events is somewhat higher than in the $\tilde{\nu}_\mu N$ events (Table I). The multiplicity $\langle N_\pi \rangle$ in the reactions with cumulative protons coincides within the limits of experimental error with the average multiplicity for the usual processes (Table II). We observed an angular asymmetry of the parameter $B(\theta)$ (Fig. 2) and a weak correlation of the variable x with the momentum of the cumulative proton (Fig. 3). The enumerated facts contradict the hypotheses.[5,6] The $\nu_\mu N$ and $\tilde{\nu}_\mu N$ events with a cumulative proton have an identical excess yield of identified protons (0.75 proton/event). The excess proton yield and the observed x-α correlation in the framework of the hypothesis[7] indicate that the three-nucleon correlation contributes significantly to the mechanism of the process. A coincidence of the $\langle N^s_{\pi^\pm} \rangle$

multiplicity and an increase of the value of $\langle N^{s}_{\pi^-} \rangle$ in the events with cumulative protons (Table II) seems to indicate that the capture of secondary $\pi^{\pm}$ mesons by a nucleon pair in the nucleus (as a mechanism for production of cumulative nucleons) is suppressed. The observed increase of the yield of slow π^- mesons was not predicted by any of the discussed theoretical schemes.[5-8]

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